

# Structural and Optical Properties of $\text{Ce}^{3+}$ Doped $\text{YPO}_4$ : Nanophosphors Synthesis by Sol Gel Method

B. Kahouadji, L. Guerbous, L. Lamiri, A. Mendoud

**Abstract**—Recently, nanomaterials are developed in the form of nano-films, nano-crystals and nano-pores. Lanthanide phosphates as a material find extensive application as laser, ceramic, sensor, phosphor, and also in optoelectronics, medical and biological labels, solar cells and light sources. Among the different kinds of rare-earth orthophosphates, yttrium orthophosphate has been shown to be an efficient host lattice for rare earth activator ions, which have become a research focus because of their important role in the field of light display systems, lasers, and optoelectronic devices. It is in this context that the  $4f^n \leftrightarrow 4f^{n-1} 5d$  transitions of rare earth in insulating materials, lying in the UV and VUV, are the aim of large number of studies. Though there has been a few reports on  $\text{Eu}^{3+}$ ,  $\text{Nd}^{3+}$ ,  $\text{Pr}^{3+}$ ,  $\text{Er}^{3+}$ ,  $\text{Ce}^{3+}$ ,  $\text{Tm}^{3+}$  doped  $\text{YPO}_4$ . The  $4f^n \leftrightarrow 4f^{n-1} 5d$  transitions of the rare earth dependent to the host-matrix, several matrices ions were used to study these transitions, in this work we are suggesting to study on a very specific class of inorganic material that are orthophosphate doped with rare earth ions. This study focused on the effect of  $\text{Ce}^{3+}$  concentration on the structural and optical properties of  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  yttrium orthophosphate with powder form prepared by the Sol Gel method.

**Keywords**— $\text{YPO}_4:\text{Ce}^{3+}$ ,  $4f^n \leftrightarrow 4f^{n-1} 5d$  transitions, scintillator.

## I. INTRODUCTION

RECENT reports demonstrate that the doped rare earth ions  $\text{RE}^{3+}$  could be the promising scintillator materials [1],[2]. Rare earth doped orthophosphates ( $\text{LnPO}_4$ :  $\text{Ln}=\text{La}$ ,  $\text{Ce}$ ,  $\text{Gd}$  or  $\text{Y}$ ) have been attracting much attention [3]. Due to the high energy band gap, high thermal and chemical stability, high luminescence quantum yield, and sharp emission bands of orthophosphate host.

Lanthanide phosphates  $\text{LnPO}_4$  crystallize in two polymorphs, that is, tetragonal phase with xenotime structure and monoclinic phase with monazite structure.

Yttrium orthophosphate  $\text{YPO}_4$  crystallizes with the zircon structure (xenotime type) with a tetragonal symmetry ( $a=b=0.6894\text{nm}$  and  $c=0.6027\text{nm}$ ) and space group  $I_{41}/amd$  [4]. Where the site symmetry for  $\text{Y}^{3+}$  ions is  $D_{2d}$  point-group [6]. The structure can be described as chains parallel to the c axis of corner-sharing structural units built of  $(\text{YO}_8)$  dodecahedron and a  $(\text{PO}_4)$  tetrahedron linked together by an edge [5], [6] (Fig. 1).

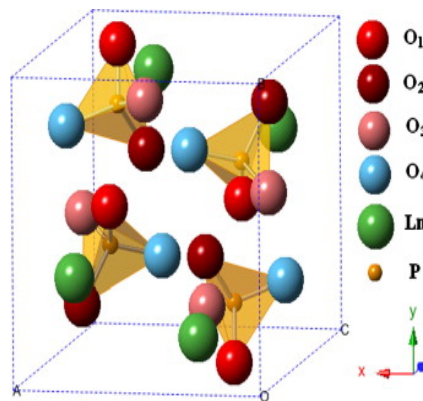


Fig. 1  $\text{LnPO}_4$  Xenotime structure

$\text{YPO}_4$  doped with  $\text{Ce}^{3+}$  ions attracts increasing interest as a good candidate for manufacturing of scintillators and phosphors because of its cheapness and the fact that its wide bandgap provides enough space for  $4f$  and  $5d$  orbitals of doped lanthanide ions [7].

To enhance luminescence intensity and scintillation efficient in any host doped with rare earth ions, the followings are the main requirements: finding out of optimum concentration of dopant ions (activator) for maximum luminescence in a host material, doping of appropriate sensitizer in the host material so that energy transfer to the activators is maximum, host with low phonon vibrations, host having transparency in visible and near-infrared (NIR) regions, stable in ambient atmosphere chemically and thermally and choose of suitable solvent/reaction medium. [8].

In the present work we have study the concentration effect of  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  host with powder form on their structural and optical proprieties because there are any study reported Clearly the concentration effect of  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  synthesis by sol gel method and the mechanism of concentration quenching is discussed in this paper .

## II. SAMPLES PREPARATION

For preparation of nanophosphors samples with powder form used in the present work we have adopted the sol gel method, four samples of  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  prepared with different concentration of  $\text{Ce}:\text{Y}_{1-x}\text{Ce}_x\text{PO}_4$  ( $x=0.5\%$ ,  $1\%$ ,  $2\%$ ,  $5\%$ ).

In a typical synthesis process, appropriate amount of  $\text{Y}_2\text{O}_3$  (99.99%),  $(\text{NH}_4)_2\text{HPO}_4$  (>99.0%),  $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$  dissolved in appropriate amount of solution (Deionized water + nitric acid) the final mixture obtained stirred for 10h after that a

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certain amount of organic additive (ethylene glycol EG) added and stirred for 2h, then the PH of solution was adjusted to 2 by addition of  $\text{NH}_3 \cdot \text{H}_2\text{O}$  solution, finally, the colloidal solution was obtained.

The resulting solution dried at  $100^\circ\text{C}$  for obtained the samples  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  samples with powder form.

### III. STRUCTURAL CHARACTERIZATION

#### A. XRD Analysis

All the powder of  $\text{YPO}_4:\text{Ce}^{3+}$  nanophosphors annealed at  $900^\circ\text{C}$  for 4h with step of  $2^\circ/\text{min}$ .

The structure of the resulting powder was characterized by X-ray Powder diffraction (X'Pert SW) with  $\text{CuK}\alpha$  radiation,  $\lambda=0.154056\text{nm}$  employing a scanning step of  $2^\circ/\text{min}$  in the  $2\theta$  from  $10^\circ$  to  $100^\circ$  range.

The XRD Patterns of  $\text{YPO}_4:\text{Ce}^{3+}$  samples prepared with different concentration of  $\text{Ce}^{3+}$  shows well crystallized tetragonal phase (Xenotime structure) according to JCPDS 09-0377 Fig. 2.

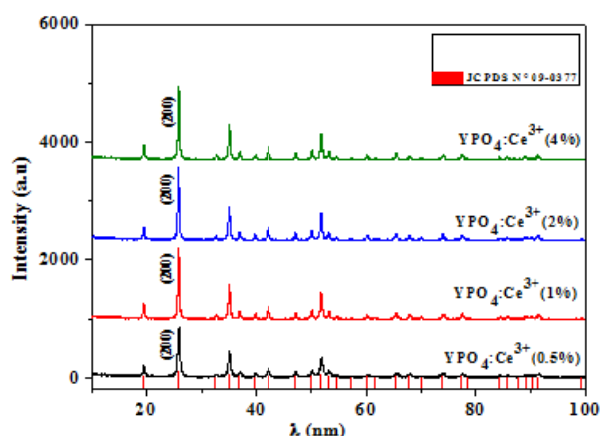


Fig. 2 XRD patterns of  $\text{YPO}_4:\text{Ce}^{3+}$  powder annealed at  $900^\circ\text{C}$  for 12h

The unit cell volume and lattice parameters of all prepared samples are calculated and summarized in Table I.

TABLE I  
UNIT CELL VOLUME AND LATTICE PARAMETERS OF SAMPLES

| Concentration (Ce%) | a (Å) | b (Å) | c (Å)  | Cell volume (Å <sup>3</sup> ) |
|---------------------|-------|-------|--------|-------------------------------|
| 0.5                 | 6.876 | 6.876 | 6.010  | 284.14                        |
| 1                   | 6.873 | 6.873 | 6.02   | 284.37                        |
| 2                   | 6.881 | 6.881 | 6.0222 | 285.14                        |
| 4                   | 6.884 | 6.884 | 6.024  | 285.47                        |

The unit cell volume of the samples increases with increasing concentration of  $\text{Ce}^{3+}$  in  $\text{YPO}_4$ , because the ionic radius of  $\text{Y}^{3+}$  ( $0.9^\circ\text{Å}$ ) [9] is less than  $\text{Ce}^{3+}$  ( $1.14^\circ\text{Å}$ ) [8]. The increase in the unit cell volume with increasing concentration of  $\text{Ce}^{3+}$  indicates the quantitative substitution of  $\text{Ce}^{3+}$  in the lattice site of  $\text{Y}^{3+}$  in  $\text{YPO}_4$  matrix.

#### B. Grain Size

After that confirmed the pure phase of the powders  $\text{YPO}_4:\text{Ce}^{3+}$  prepared with sol gel process we have calculated the grain size of this powders.

The average crystallite size ( $D$ ) was calculated from Scherrer relation [10]:

$$D = 0.89 \lambda / \beta \cos \theta \quad (1)$$

where  $D$  is the effective particle size,  $\beta$  is FWHM,  $\theta$  is the diffraction angle,  $\lambda$  is the X-ray wavelength, the coefficient 0.89 is used to correct the particle size.

Fig. 3 shows the variation of grain size with Ce concentration.

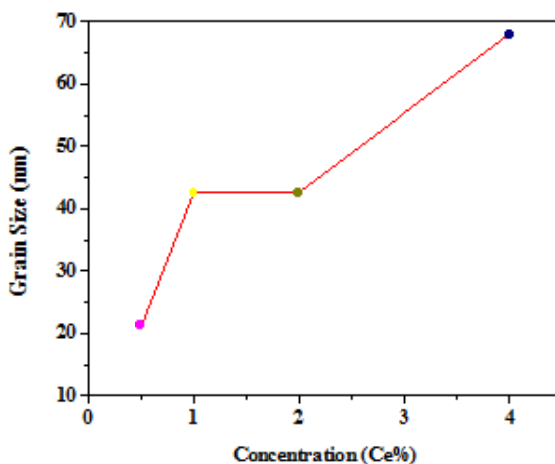


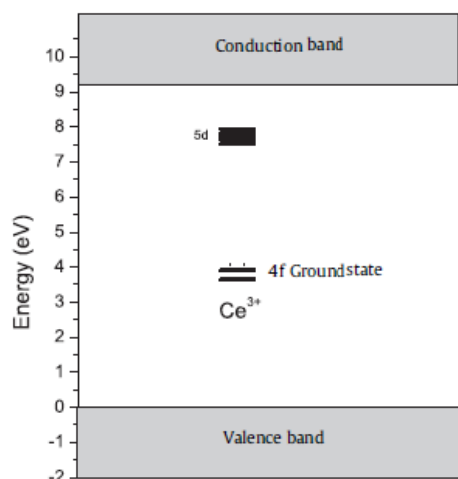
Fig. 3 Grain size of  $\text{YPO}_4:\text{Ce}^{3+}$  nanophosphors calculated from Scherrer formula for (200) plane

### IV. PHOTOLUMINESCENCE STUDY

The interconfigurational  $4f-4f5d$  spectroscopy of the nanopowder  $\text{YPO}_4:\text{Ce}^{3+}$  was measured using Perkin Elmer LS 50B luminescence spectrometer equipped with a 150 W Xenon lamp in the range of 200nm-800nm.

#### A. $\text{Ce}^{3+}$ Ion Spectroscopy in $\text{YPO}_4$ Matrix

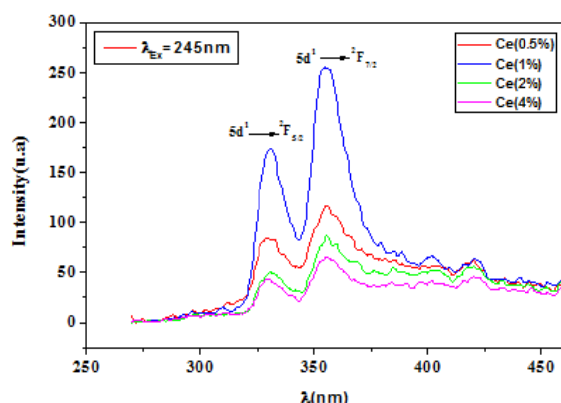
Fig. 4 shows the  $4f$  and  $5d$  levels of  $\text{Ce}^{3+}$  ion in the  $\text{YPO}_4$  host [11].

Fig. 4 4f and 5d levels of  $\text{Ce}^{3+}$  ion in  $\text{YPO}_4$  host

It's very clearly that the  $\text{YPO}_4$  hosts appropriate to get the good efficient luminescence for  $\text{Ce}^{3+}$  ion doped  $\text{YPO}_4$  because it provides the very large space for 4f and 4d levels of  $\text{Ce}^{3+}$ .

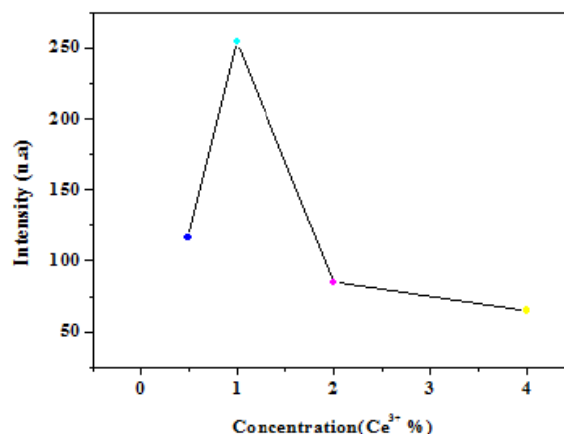
#### B. Emission Spectra of $\text{YPO}_4:\text{Ce}^{3+}$ Nanophosphors

The emission spectra of the samples under excitation  $\lambda_{\text{ex}} = 245\text{nm}$  are shown in Fig. 5.

Fig. 5 Emission spectra at room temperature of the  $\text{YPO}_4:\text{Ce}^{3+}$  samples studied under  $\lambda_{\text{ex}} = 245\text{nm}$ 

All spectra emission of nanopowder are studied in the spectra range of 260nm-450nm, The emission spectrum taken at an excitation wave length of 245 nm shows two emission bands centered at 330nm and 355nm, One relatively weak band peaked at 330 nm may be ascribed to the transitions from the excited state levels, which is the lowest crystal-field component of the  $5d^1$  configuration to the ground state levels  $^2F_{5/2}$  of the  $4f^1$  configuration of dopant  $\text{Ce}^{3+}$  [12], other band attributed to the  $5d^1 - ^2F_{7/2}$  transition.

The intensity of each band increase with increasing of the concentration of  $\text{Ce}^{3+}$  in the  $\text{YPO}_4$  host between 0.5% and 1% after that the intensity of bands decrease with increasing of the concentration of  $\text{Ce}^{3+}$ , Fig. 6 shows the variation of luminescence intensity of  $5d^1 - ^2F_{7/2}$  transition with  $\text{Ce}^{3+}$  concentration.

Fig. 6 Effect of  $\text{Ce}^{3+}$  concentration doped  $\text{YPO}_4$  on the luminescence intensity of  $5d^1 - ^2F_{7/2}$  transition

The results of luminescence quenching in Fig. 6 show that, for the  $\text{YPO}_4:\text{Ce}^{3+}$  nanopowder, the optimum dopant concentrations of  $\text{Ce}^{3+}$  ions is 1%.

#### C. Chromaticity Coordinates

For understand the luminescence color of the  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  samples after excitation ( $\lambda_{\text{ex}} = 245\text{nm}$ ) we have calculated the chromaticity coordinates.

Table II shows the chromaticity coordinates ( $x, y$ ) of  $\text{YPO}_4:\text{Ce}^{3+}$  nanophosphors and respective color from CIE diagram.

TABLE II  
CIE COLORS COORDINATES ( $X, Y$ ) OF SAMPLES

| Concentration (Ce%) | $x$     | $y$     | CIE Color |
|---------------------|---------|---------|-----------|
| 0.5                 | 0.16309 | 0.01219 | Blue      |
| 1                   | 0.163   | 0.01230 | Blue      |
| 2                   | 0.1629  | 0.0123  | Blue      |
| 4                   | 0.1629  | 0.0123  | Blue      |

#### V. CONCLUSION

- $\text{YPO}_4:\text{Ce}^{3+}$  nanophosphors are successfully synthesized through sol-gel method at moderate temperature (900 °C)
- The prepared  $\text{YPO}_4:\text{Ce}^{3+}$  crystallizes in a single-phase, Tetragonal structure.
- In this study the influence of  $\text{Ce}^{3+}$  concentration doped  $\text{YPO}_4$  host on their structural and optical proprieties is confirmed, So, we have given the emission spectra of  $\text{Ce}^{3+}$  doped  $\text{YPO}_4$  with difference concentration (0.5%, 1%, 2%, 4%) under excitation  $\lambda_{\text{ex}} = 245\text{nm}$ .
- Finally, the mechanism of luminescence quenching in the  $\text{YPO}_4:\text{Ce}^{3+}$  is studied; the optimum dopant concentration is 1%.

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